Ergonomic Wheelchair Team

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Design Team

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Abstract

Our client, Noah, has a medical condition that causes decreased muscle coordination and strength, so it is difficult for him to push traditional wheelchairs by gripping the wheel rims and moving them forward. Fully motorized wheelchairs controlled by a joystick require little to no energy exertion from the user, however, Noah must exercise routinely to maintain his strength and mobility. His unique physical needs illustrate the gap in mobility products between automated and manual wheelchairs. Through research, design, iteration, and testing, the team developed a wheelchair customized to Noah's capabilities involving a mechanical and electrical system. The electrical system uses DC motors to power friction-drive rollers mounted on the rear wheels of the wheelchair. The friction-drive rollers are made from rubber, and, when in contact with the rear wheels, create enough friction to rotate the wheel and drive the wheelchair forward. The mechanical actuation system features linear guide rails attached to the arm rests that Noah uses by gripping handles and moving them in a straight sliding, back and forth movement. This horizontal movement is like a chest press exercise, which is approved by Noah's physical therapist. A sensor is incorporated to recognize the rate at which Noah is conducting his movements and translate that information as input to the motor to tell it how fast it needs to operate for the wheelchair to reach the desired speed. Buttons integrated onto the handles are used as the control center for turning. The team also incorporated a mode in which the wheelchair movement is controlled entirely by these buttons, requiring no physical exercise in the event Noah becomes too fatigued to continue traveling. This ergonomic wheelchair overcomes the shortcomings of today's standard wheelchair; it gives Noah the opportunity to move around independently by incorporating his physical therapy exercises as his means of mechanical propulsion with electrical assist.

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Need

Wheelchairs are a convenient way to get around for people with reduced lower body capabilities. Typical manual wheelchair users propel themselves using the wheel hand-rims method which requires high mechanical demand. This mechanical demand is completely reliant on the user's input. The repeated motion can cause shoulder joint strain due to the abrupt direction and speed fluctuations of the stroke pattern [1]. These factors create a need for alternative designs of wheelchairs, so users can physically propel themselves forward in a manner that meets their capabilities and will not cause long term strain. The goal of this project is to develop an alternative manual propulsion system that overcomes the ergonomic shortcomings of today's standard wheelchairs, specifically for a client who has a physical disability that limits muscle coordination and strength throughout their entire body. This customized solution uses propulsion mechanisms and movement requirements that involve beneficial exercise movements based on their physical therapy recommendations and eliminates the risk of injury or unnecessary fatigue.

Background and Significant Prior Work

When designing a wheelchair solution for a specific person some of the best research involves firsthand interviews with the intended user to gain direct feedback. Before the group can ask educated questions to stakeholders of the project, it is important to understand the situation. With this, the group aimed their research to understand the basic concepts of possible actuation mechanisms and linking this to the biomechanics of someone with similar physical needs to the intended user of the project. The group also investigated existing solutions. There are many groups that have had similar goals in their projects and have made tremendous advances that the group can take inspiration from.

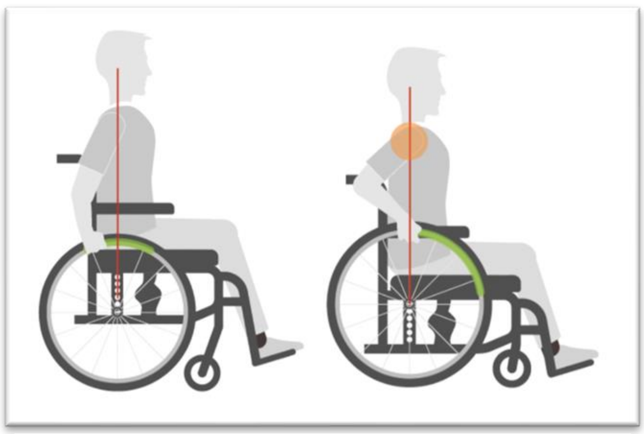

Figure 1: The most common hand-rim propulsion technique for the user to manually propel the wheelchair. This causes stress and strain in the shoulder joint and can cause injury from overuse.

Today's wheelchairs are mostly limited to either fully mechanical, which is propelled by the user manipulating the wheels, or fully electric, with the user operating a joystick to power the wheelchair. There are current products on the market where a hand lever system is incorporated to mitigate the strain on the shoulders, elbows, and the wrist region commonly caused by the push rim propulsion movement used on a traditional wheelchair [2]. The push rim propulsion movement is the most common technique; however, it is energetically inefficient because the upper body movements are discontinuous due to the constant release and grabbing of the wheel. The first wheelchair solution the group researched is a prototype using a rowing motion to move the wheelchair rather than the current hand-rim system [3]. While this system relies more on the stronger and larger back muscles, the drive mechanism is a cable-pulley system that requires a considerable force input that is not sustainable for the intended user. Also available on the market is the Wijit Driving and Braking System that is retrofitted to standard wheelchairs [4]. This system is lever-propelled, the user pushes the lever down to create enough torque to propel the wheelchair a short distance. While the levers are positioned in a more ergonomically comfortable position, it shares the same concerns as Handwheelchair.q. The amount of force required to propel the wheelchair a short amount is too great for the user, and the product is marketed for $5,000, which is unrealistic as an affordable option.

Although these systems are more ergonomically effective than the standard wheelchair movement, it requires a lot of strength from the hands, especially when the user is gripping the handle. Because of this, the group decided to also implement an electrical system to assist the user and supplement the needed power to drive the wheelchair. The group shifted their focus to systems that implemented both mechanical and electrical systems. There is not a saturated market for wheelchairs that incorporates both systems, especially because most electric wheelchairs are controlled by joysticks with no mechanical input. The group did find products and projects that used e-Bike electric components and required movement from the user. There is a niche market within the e-Bike community where people are trying to effectively incorporate motors, throttles, braking systems, and other e-Bike components onto wheelchairs to create an accessible trike.

Figure 2: The Mountain Trike is a marketed product that is sold worldwide. It is a fully customizable product and is an ideal prototype which successfully accomplishes our project goals but comes at a very steep price.

The most prominent product the group found inspiration from is the eTrike by Mountain Trike as shown in Figure 2, which is operated by the user manually pushing drive levers to power the electrical assist [5]. The electrical system is a Hub motor connected to the back frame of the wheelchair. On the lever handles of the eTrike, that the user manipulates to drive the wheelchair, there are throttles so the user can control the amount of power assist and steer. A purely mechanical input from the user can drive the wheelchair because there is a chain and sprocket system connecting the drive levers and wheels. The group consulted with their expert design reviewer Gerry from BostonEbikes about implementing components like the Hub motor, lever arms, throttle, steering system, and braking system from the eTrike. Gerry is an expert in converting mechanical bikes to e-bikes and adapting throttle mechanisms to fit various client's needs, so the group valued his opinion. Gerry shared potential concerns the team could run into when trying to implement components of the eTrike system [6]. For example, designing, mounting, and executing the steering of a third wheel would not be feasible given the time and monetary constraints of this project. Gerry recommended using off-the-shelf friction drive rollers, which were popular in the very early days of eBike conversions, on the two back wheels of the wheelchair to eliminate the complications of adding a Hub motor to the back frame and to provide the desired power assistance.

The last significant work in the group's research phase was a DIY project using Arduino to drive friction motors to electrify a manual wheelchair [7]. The friction rollers are placed in close contact with the large rear wheels on the wheelchairs so friction can be utilized as the primary source of engagement to rotate the wheels. In the DIY project, Arduino code is used to control Nema17 stepper motors, and the system is powered by a rechargeable battery. The materials used in the project were low cost because the support structure for the electrical components like the Arduino, battery, and motors were 3D printed. This project is fully electrical, a joystick controls the movements of the wheelchair. However, the group found the simplicity of the components of the project, and, more importantly, the ability to iterate and customize the design to be valuable. The group decided to inspire the electrical system of their project based on this DIY project and integrate their own mechanical system. The group's design solution will be further explained in the following sections.

Design Solution

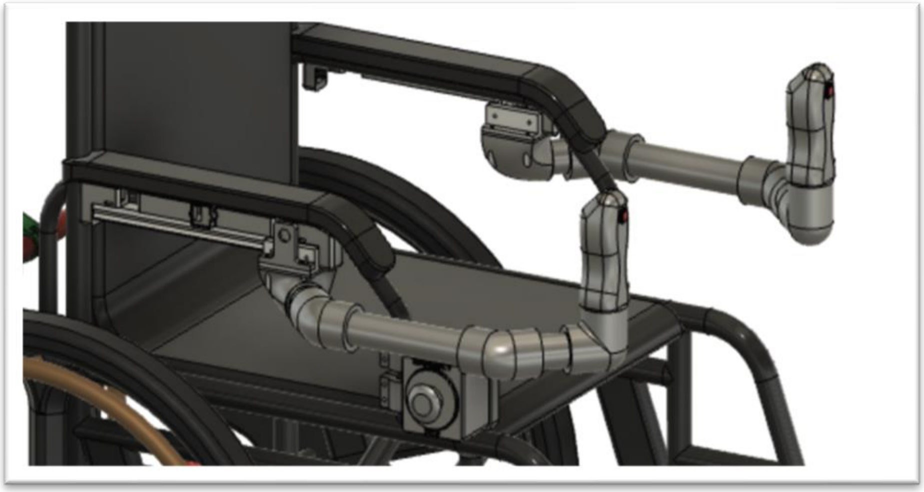

Figure 3: The mechanical input system designed using a modeling software. The linear guide rails mounted under the arm rests are shown along with attached PVC which will the connect to the handles that will be operated by the user. The trigger buttons are shown in red, and the emergency stop is shown below the moving arm.

The final design consists of two main systems, an electrical and mechanical system, working together to enable Noah to independently move around using movements that are within his ability. Noah did not want a wheelchair that was strictly electric, operated by a joystick; he wanted a way to incorporate rehabilitation movements that would provide routine exercise. The user interface in the final design is specialized to Noah's capabilities and supplements the interworking system.

For the mechanical input, the final design features a linear guide rail attached to the arm rests that interacts with the motors by a sensor that recognizes the movement of the user. The linear guide rail is actuated by the user gripping handles that restrict movement to a straight sliding, back and forth movement. This horizontal movement allows Noah to perform a chest press motion, which reduces stress on his shoulders and is a motion approved by his physical therapist. This aspect of the wheelchair design was completely customized to the capabilities and needs of our client. The group was cognizant of the long-term risks of wheelchair use, including fatigue failure, as well as reproducing, in this design, the chronic injuries caused by standard wheelchair use. To assist Noah and reduce fatigue, the Capstone group decided to include sensors so that the speed at which the user slides the handles up and down the guide rail is proportionally related to the speed of the motor. For example, if Noah increases the speed of the handle, the motor speed will increase, and the wheelchair will move faster. Hall effect sensors are implemented to sense how long one full path of the guide rail takes and translate that information to the motor to tell it how fast it needs to operate for the wheelchair to reach the desired speed. The hall effect sensor is also to aid with Noah’s varying muscle strength, fatigue levels, and mobility on a day-to-day basis. Since he may not be able to provide a consistent power input when using the wheelchair, he can rely on the hall effect sensor and motor to assist as needed.

Figure 4: The hall effect sensor mounted in the custom 3-D printed bracket. The magnet that is used to activate the sensor and send signals to the motor is shown on the left, mounted on the moving slider.

For the electrical side, the final design is two friction drive rollers placed in direct contact with the rear wheels that are used to transfer power from two motors to rotate the wheels. The motors, as well as the sensors and other electrical components, are powered with a rechargeable

12V lead acid battery that is secured to the wheelchair. Because modifying the frame of the wheelchair is not preferred due to the risk of buckling, the team decided to 3D print supports inspired by the DIY Arduino project to mount the friction rollers. The 3D printed supports are used to clamp PVC pipe onto the aluminum frame of the wheelchair to create a platform, so the battery, motors, and friction drives can be elevated and fixed in their respective place. The friction rollers are made from rubber, which when in contact with the wheelchair wheel, creates enough friction to rotate the wheel and drive the wheelchair forward. The team chose the electrical design because of its low cost, simplicity compared to adding a Hub motor, and ability to tap into the code and customize the motor controller. The turning, reverse, and safety feature interface is personalized to the user's needs for desired control of the motors.

For the user interface, there are two handles that will be gripped by the user to activate the mechanical actuation as shown in Figure 3. There are buttons that can be triggered by the pointer finger on each handle. The wheelchair has two modes: fully electric or assistive mode. In the assistive mode, the user will use the buttons for steering and the chest press motion of the linear guide rail to accelerate the wheelchair. The movement of his arms performing the chest press motion will engage the motor and tell it to accelerate. To reverse, he must press both buttons at the same time. For the fully electric mode, moving forward requires both buttons to be pressed, which is a different command compared to the assistive mode. To reverse, he must engage the assistive mode and use the same commands. Switching modes can be done using a switch on the left side of the wheelchair. As an added safety measure, there is an emergency stop button located on the right of the wheelchair that will tell the motor to gradually slow the wheelchair to a stop.

The combination of mechanical and electrical systems allows Noah to choose what mode he wants to use based on his energy levels. If he is feeling heavily fatigued, he can use the buttons to fully control his motion. If he wants to use his own mechanical input to move, he can actuate the linear rail by performing a chest press motion and the sensor will pick up on his movement to accelerate the chair.

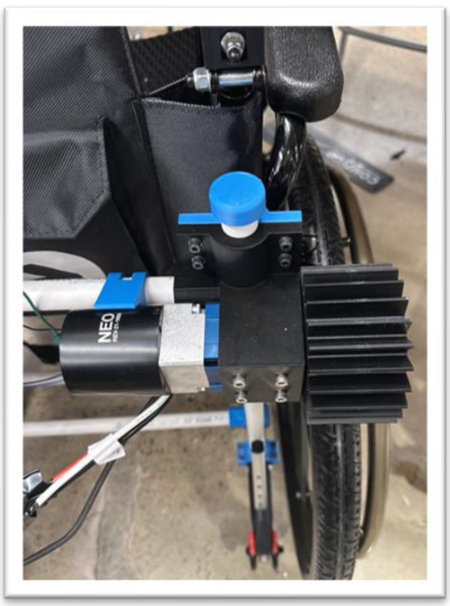

Figure 5: The electrical system including, from left to right, the motor, gearbox, and 3-D printed roller mounted atop the rear wheel. The black bolted component is a custom 3-D printed part used to secure the gearbox and mount it to the chair.

Design Process

After meeting with our client to discuss his physical capabilities and typical energy levels throughout the day, the team began brainstorming design ideas for the mechanical actuation system. Simultaneously, the group was meeting with Gerry from BostonEbikes for feedback about motor types and adapting existing bike systems safely and efficiently. Although other design ideas such as adding an extra wheel to the wheelchair or adding hub motors to the existing rear wheels were considered, these conversations ultimately led to the decision to use friction driver rollers mounted on the rear wheels to propel the wheelchair using DC motors. Because these rollers are always attached to the wheels, the mechanical system must be independent of the wheels themselves and would only speak to the motors through sensor input.

The group briefly considered implementing a chain and sprocket system that would attach to the rear wheel of the chair, like on a bike and seen on the eTrike, but decided for this phase of the project it was not feasible given the presence of the rollers on the wheels. This system would have had linear arm handles that the user would press forward and down, and then bring back to its neutral starting position for one complete cycle. However, because of Noah's varying strength, gearing would have had to be implemented so the resistance could be controlled by the user; choosing one gear ratio would not have worked for his specific needs. There was also difficulty figuring out how to not cause generator effect in the motors, because if both the chain and sprocket is rotating the wheels as well as the friction motors, there is a high possibility the combined rotational motion would cause an excess of voltage and fry the motor. Due to these concerning design flaws, it is clear the mechanical design chosen by the group was the best option for both mitigating these concerns and fitting the user's needs.

Using specifications from the Mountain Trike and the DIY project, the team gathered information based on the client's weight, force input, and ideal wheelchair speed to assess which motor would be ideal for the design. This prompted an investigation into the expected loading that the system will experience, how it will be distributed across the wheels, and how this translates to the required power of the motor. Calculations were performed to determine the minimum power needed based on different velocities and friction coefficients. For a "worst case scenario" requiring the maximum power to achieve a speed of 1.5 m/s and a friction coefficient of 0.3, the power required would be 137.05 Watts. From these calculations, the team decided to utilize the Vex NEO brushless DC motors, which provide a peak power of 500W, nearly four times greater than the calculated power required to rotate a rear wheel.

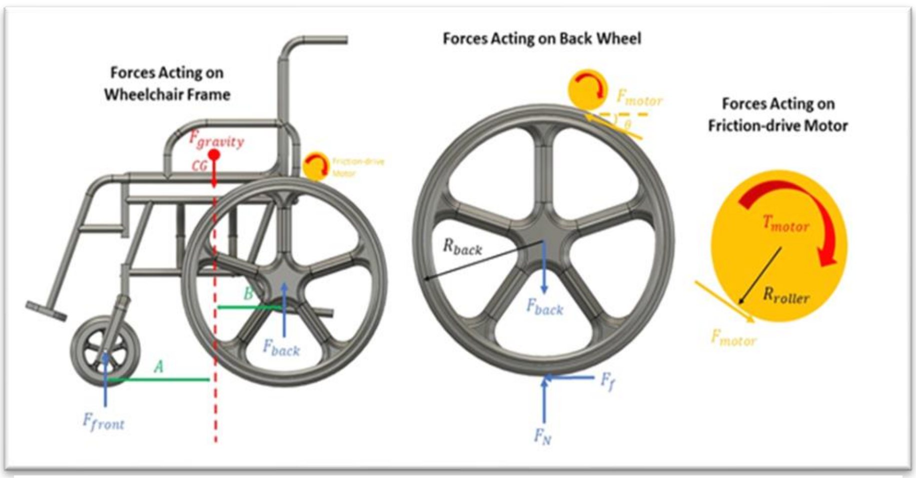

Figure 6: Force diagrams were made for calculations of the power required to meet the calculated torque values. These were used to spec the motor necessary to meet the desired minimum speed requirements.

Based on the specifications of the motor, the team settled on a desired motor speed of 4,500 RPM to maximize performance, which would need to be geared down to set the rear wheel rotational velocity at the desired speed of approximately 45 RPM to a velocity of 1.5 meters per second. The initial plan was to utilize just a geometric ratio between the diameters of the friction roller and the rear wheel to transition from the motor speed to the rear wheel speed. However, a ratio of approximately 100:1 was deemed necessary to achieve the desired velocity, which was determined insufficient as the much smaller friction roller would likely not achieve the engagement required and lose power due to slip. As a result, the team will utilize a 6:1 ratio between the diameters of the rear wheel and the friction roller, as well as an additional 16:1 gearbox between the friction roller and the motor shaft to achieve a total transition of 96:1.

The friction drive roller design was originally inspired by the DIY research project. The goal was to create a surface that would provide high friction between the roller and the wheel to limit the risk of slipping. For the first iteration, rollers were 3-D printed so motor testing could begin to achieve movement of the rear wheel by the motor. It was important to determine the necessary mounts to ensure there was satisfactory engagement between the roller and rear wheel early in the design process before finalizing the materials. The team later decided to purchase off-the-shelf rollers to ensure longevity and consistent performance. The rollers on the final design are made of urethane, a material with a higher coefficient of friction than others tested by the team. A shaft collar was also needed to properly mount the roller on the shaft of the gearbox.

Once the team had determined the essential mechanical and electrical components needed to propel the wheelchair, materials for mounting and fabricating the parts were selected. PVC was selected for the framework for mounting the system components to the chair. 3-D printed brackets with bolts and square nuts would clamp the PVC and other mounting components to the existing framing of the chair. Custom supports were designed to hold selected gearboxes and motors as shown in Figure 7.

For the propulsion system, the goal was to make a seamless integration of the linear guide and slider system. Parts sticking out of the chair are a safety hazard and can be broken easily if something fell on the chair or the client leaned on it when getting in and out of, so the group was thoughtful of this when designing. To incorporate the chest press motion discussed previously, the team decided on a setup consisting of PVC fittings and tubing to connect the slider to handles that is in a comfortable resting position for the user. Testing with people of similar stature to the client informed the height and placement of the handle.

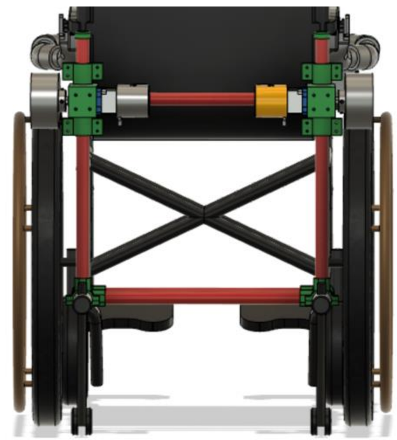

Figure 7: The framework of PVC (red) used to mount the electrical components (yellow) secured with 3-D printed brackets (green) on the back of the wheelchair. The rollers are shown in grey above the rear wheels.

The user interface was an important consideration when designing the mechanical propulsion system and controls of this prototype. The team made it a priority to not overload the number of buttons and trigger points on the wheelchair, emphasizing simplicity. From the group's meetings with Gerry, having a cutout or failsafe was a top priority because the motor would need to disengage in case of an unforeseen emergency or situation. The group decided on an emergency stop button on the right frame of the wheelchair. The second design consideration was turning the wheelchair right or left. For safety, and so the user has a backup option in case their energy levels are completely depleted, having the choice to operate the wheelchair without a mechanical input and only by engaging the buttons was necessary. Because of this, the group decided the buttons will be resting comfortably by the user's trigger fingers on the right and left handle. The user can then easily use the buttons to turn the wheelchair and, if need be, to completely control the wheelchair.

To accomplish all these tasks in a limited amount of time, the team divided tasks into two main categories: mechanical and electrical. Half of the group worked on motor control, writing code for communication with the motor controllers, hall effect sensors, buttons, battery selection and charging. The other half worked on using modeling software to combine all the system components and wheelchair based on their respective specifications along with the user interface. This informed the design of the framing system, custom brackets, and mounts for the electrical components. Following the first set of prints, the team assembled the parts onto the chair and iterated as needed.

Results

As described above, the wheelchair consists of a mechanical system using a linear motion comfortable for Noah and an electrical system comprised of friction drive rollers for power assistance. The wheelchair is programmed to add variable power assistance when needed. It has capabilities to turn left and right, an emergency stop for safety, buttons to control the fully electric mode and turning in the assistive mode, and reversing. The components of the wheelchair are low cost and convenient, making use of 3D printing and common off the shelf products.

The first step of testing was successfully mounting the friction drive motors to the wheelchair and controlling the motors with the buttons. Once the wheelchair was able to move and turn someone sitting in the wheelchair, the next step was integrating the mechanical system, hall effect sensor, and user interface. Perfecting these components and having them work together seamlessly was the final step to a complete prototype that we could test safely with our client.

Summary and Impact

Figure 8: Our client, Noah, sitting in the chair before testing the prototype.

By developing this prototype, Noah will have the opportunity to move around independently, and incorporate his physical therapy exercises as the means of mechanical propulsion. The system was built for our client's specific needs and physical abilities. It allows for flexibility of mode of operation based on his fatigue levels, which has been the limiting factor that has required our client to rely on a transport chair pushed by someone else to get around for his entire life. Having the electrical component of the wheelchair allows Noah to have confidence that he will never be too exhausted to continue to move himself around. A lot of attention was focused on the user interface and safety features to ensure Noah would be comfortable and able to access and operate all the necessary braking and turning controls on the wheelchair smoothly.

While this project centered around developing an adapted ergonomic wheelchair for a specific client, this combination system involving an electrical component and a unique mechanical propulsion system could be used by other teams developing similar prototypes. It would be ideal for wheelchair users who still wanted to incorporate exercise and movement into their lives without resulting in increased strain or stress on their shoulder joints with the commonly used hand-rim propulsion system.

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